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SPECTRAL, ELECTROPHOTOMETRICAL, AND RADAR RESEARCHES OF AURORAE AND AIRGLOW

COLLECTION OF ARTICLES

V. I. Krasovskiy, Editor

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Translation of "Spektral'nyye, elektrofotometricheskiye i radiolokatsionnyye issledovaniya polyarnykh siyaniy i svecheniya nochnogo neba. Sbornik statey." IGY Program, Section IV, No. 6, USSR Academy of Sciences Press, Moscow, 1961.

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I. PREFACE

The material on the subject of "Spectral, Electrophotometric, and Radar Researches of Aurorae and Airglow" published in Collections Nos. 1, 2-3, 5 and in various journals, as well as in the present collection, is the result of continuing processing of observation data for the individual problems. An ultimate generalization can be made only after all the processing has been completed.

The results of electrophotometric observations of night-sky emission published in this collection differ somewhat from results obtained by means of spectrographs. This is apparently explained by the fact that when the data from electrophotometric observations are processed according to the accepted international system, the continuum is assumed to have a constant relative spectral distribution. However, the works of N. N. Shefov and V. I. Yarin (Collection No. 5) do not permit such an assumption to be made, at any rate not conclusively. Apparently serving also to confirm this is the fact that accounting for the continuum according to the accepted system of processing electrophotometric data sometimes leads to the negative-emission-intensity values of (OI) λ 6300 Å and Na λ 5893 Å. Such a considerable effect of the continuum is due to the great width of the transmission band of the interference filters used (effective width is about 100 Å).

A correlation between the (OI) λ 6364 Å and OH emissions has been detected by V. S. Prokudina (Collections No. 2-3 and No. 5). Processing of data obtained at Yakutsk (see V. I. Yarin's article in Collection No. 5) has, however, shown that such a correlation is observed only for low intensities of hydroxyl emission.

The seasonal variation of the rotational temperature of hydroxyl is clearly evident from the article by L. M. Fishkova and G. V. Markova, published in the present collection, as well as from V. I. Yarin's article (Collection No. 5). However, no obvious dependence of hydroxyl emission intensity on rotational temperature is observed. Such a varied nature of the behavior of hydroxyl emission is apparently explained by the complex mechanism of its excitation.

At first glance there appear to be some divergences between the material published in A. B. Korotin's articles in the present collection, and that published earlier by Yu. I. Gal'perin (Collection No. 1). It seems to us, however, that a complete correlation between radio reflections and hydrogen emission cannot be expected. Geomagnetic perturbations are an integral effect of current systems above a considerably larger portion of the earth's surface than is the limited surface above which hydrogen emission can be observed by means of a spectrograph. It will apparently be possible to obtain more complete correlation from a comparison of world magnetic indices and complete world data on auroral emissions.

In articles on radar reflections from aurorae by various authors (V. I. Pogorelov, Collection No. 2-3; V. I. Dovger, the present collection), various points of view on the reflecting regions of aurorae are expressed. It seems to us, however, that in studying the problem of which zone of the aurora reflects, it is necessary to account precisely for the refraction of incident and reflected radio waves in the inhomogeneous ionosphere. A final answer to this question can be obtained only after the effect of refraction has been completely accounted for.

In discussion of the results of radar observations of aurorae, it has also turned out that great caution must be used when comparing the intensities of radio reflections at different locations, since there are serious doubts as to the complete identity of the characteristics of different radar sets. Since the operation of radar sets is not always accurately controlled, caution is necessary in answering questions about variations in the intensity of radio reflections over long periods of observation, for example, seasonal variations. This, of course, is not important in evaluating diurnal variations of radio echoes.

II. BACKSCATTERING OF RADIO WAVES BY AURORAE

by V. I. Dovger

As was shown in references (1, 2, 3, 4), reflections of meter radio waves from ionization regions are observed during auroral displays. Until recently it was supposed that these radio echoes are due to the fact that, in individual portions of the ionized auroral regions, for the sounding frequency the electron density is higher than the critical density. Booker (Ref. 2) was the first to show that the observed amplitude values of radio echoes from aurorae could be explained by small fluctuating perturbations of electron density in the E_S- layer, the average value of this density corresponding to a critical wavelength of 20-30 meters. As do many other investigators, Booker assumes that the scattering elements extend along the lines of force of the earth's magnetic field, as a result of which maximum backscattering occurs when the beam of radio waves is perpendicular to the line of force of the earth's magnetic field in the scattering region. This question was studied geometrically by Chapman (Ref. 1).

Investigations of radio wave backscattering by aurorae were carried out systematically on Dickson Island during and after the IGY. A special installation, consisting of two radars operating on wavelengths of 4 and 6 meters, was used for pulsed radar sounding of aurorae. The reflected signals were observed on plan position indicators and on a combined range-amplitude indicator.

The chief parameters of the apparatus during the period from August 1958 to May 1960 are shown in the table.

Parameters of Apparatus	Radar Set: 4-meter	Radar Set: 6-meter	Comments
Pulse Duration, microsec	10	10	Corresponds to length of simultaneously scattering volume of 1500 meters.
Pulse Power, kilowatts	100	50	The three parameters were compared by means of artificial targets.
Antenna Power Gain	30	10	
Receiver Sensitivity at noise level (signal/noise = 1), watts	10^{-14}	10^{-14}	

In the overwhelming majority of cases, radio echoes from aurorae were observed at Dickson Island in the northern part of the sky. The direction of maximum appearance of radio echoes is close to geomagnetic north. During the years of a maximum in solar activity, 1957-1958, there were cases of reflections appearing in the southern part of the sky;strong echoes from the south appeared much more frequently on 6 meters than on 4 meters. This indicates a less complete observance of the rule of perpendicularity of the radio beam to the line of force of the earth's magnetic field (Ref. 1) at a wavelength of 6 meters.

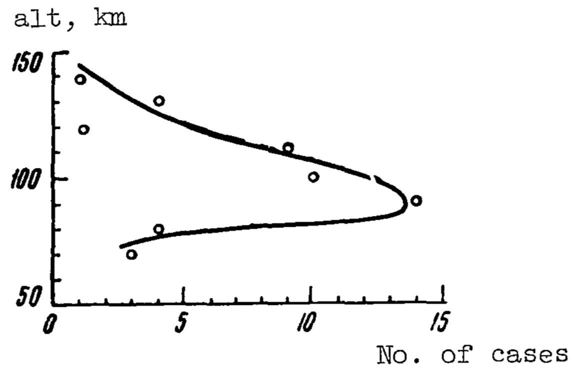

Fig. 1. Distribution in altitude of the number of reflections from aurorae.

The altitude of the reflecting sectors was measured to within ± 10 kilometers by means of rocking the antenna radiation pattern of the 4-meter radar in elevation. Figure 1 shows the distribution of the number of reflections with respect to altitude. As is evident, the majority of radio echoes comes from an altitude of 100 ± 20 kilometers. The comparatively small spread of scattering regions in altitude allowed us to plot their geographical distribution radially from 200 to 1200 kilometers from the radar set with the aid of the range-azimuth indicator (plan position indicator).

The radiation pattern of the receiving antenna for the plan position indicator is shown in Figure 2. The pattern is composed of two identical main lobes in the horizontal plane with a comparatively deep trough in the center (1/250 of the maximum in voltage E^2), which made it possible to measure the azimuth of the center of the reflecting sectors within ± 0.5 to 1.0 deg. In the case of strong radio echoes, one usually observes simultaneously a group of scattering sectors disposed approximately in an arc. An example of such reflections, as seen on a range-azimuth indicator, is shown in Figure 3.

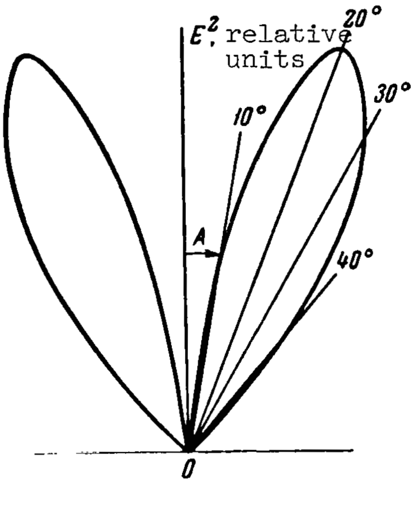

Fig. 2. Radiation pattern of the azimuthal antenna in the horizontal plane.

The coordinates of the scattering elements correspond to the centers of the "troughs" between the bright arcs. More frequently, reflections come only from individual sectors of such a line. The length of these sectors is not less than 15 kilometers and often reaches 300-400 kilometers. Range resolution of the radars was 2 kilometers.

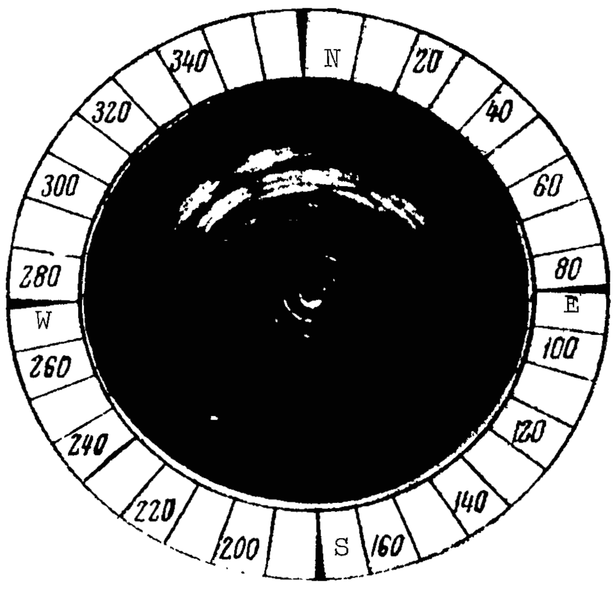

Fig. 3. Arrangement of a group of scattering areas in the vicinity of the radar set.

Direct measurements of the coordinates of the centers of the ionized sectors by means of plan position indicators disclosed movement (drift) of these at speeds of up to 1000 meters/sec. The velocity most frequently encountered was 150-300 meters/sec in the direction west to east or east to west. During drift, the signal amplitude varied greatly (by a factor of 10-15), but the speed and direction of drift remained constant. Groups of reflecting areas ordinarily moved in one direction and at one speed. Figure 4 shows the movement of such a group from the beginning of its development to the end.

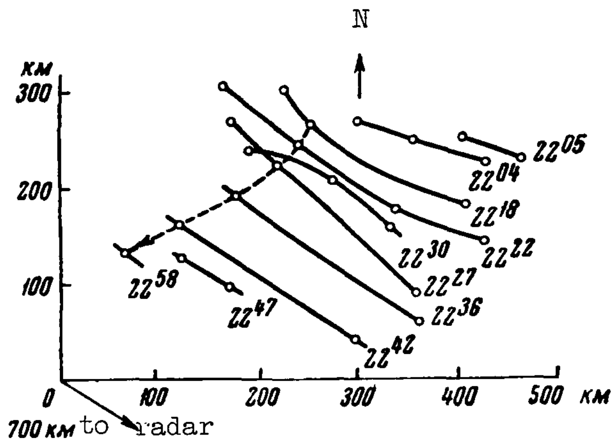

Fig. 4. Development, drift, and attenuation of an ionized arc. Local time.

With respect to the dimensions of the individual ionized sectors we can say the following. It was said above that their extent along an arc, as directly observed, varied from 15 to 400 kilometers. The extent of the elements across the arc probably does not exceed 20 kilometers, since otherwise the extent of elements 20-30 kilometers long along an arc would not have been noticeable on the plan position indicator (see Figure 3). At the same time the extent of elements across the arc is greater than 5 kilometers, inasmuch as otherwise the inner edges of the arcs would have been sharply defined for reflected signals of considerable amplitude (signal/noise = 5-10) since the "trough" of the pattern of the two-lobe antenna was deep (1/250 of the maximum in voltage) and sharp, this having been verified with the help of a discrete artificial target.

Visual observation of the reflecting portions of aurorae showed that radio reflections come always from unhomogeneous, weakly luminescent regions of the aurorae, most frequently from the lateral edges of radiant arcs. Figure 5 is a photograph of a scattering region in an aurora.

Fig. 5. An aurora sector reflecting a 4-meter wave (the distant, weak formation in the lower middle of the photograph is doing the scattering).

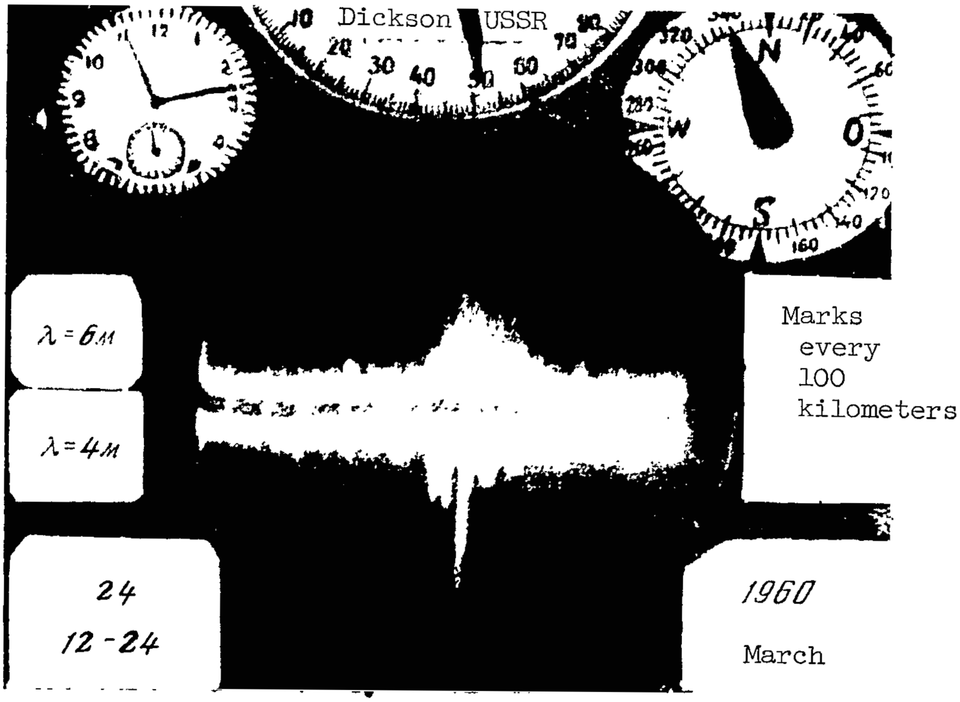

Fig. 6. Appearance of scattered signals on the range-amplitude indicator.

The backscattering coefficients were studied on a combined range-amplitude indicator (Figure 6). The antennas of the two radars, just as for the range-azimuth indicator, had the same radiation pattern in the vertical plane. The somewhat greater width of the radiation pattern of the antenna of the 6-meter radar in the horizontal plane, as compared with that of the antenna of the 4-meter radar, did not introduce significant errors. The antennas rotated rapidly and synchronously in azimuth. The solid angle of the radar beam usually overlapped the entire reflecting region. The greatest values of the integral backscattering coefficient attain several square kilometers. On the average, the backscattering coefficient for the 6-meter wavelength was 20 times as great as that for the 4-meter wavelength. The investigation results were interpreted with the aid of the formula for the integral backscattering coefficient at inhomogeneities of fluctuating volume which was derived by Booker under the assumption of a Gaussian correlation function (Ref. 4):

$$\int_v \sigma\, dv = \frac{p\omega\pi^3}{2} \cdot \frac{1}{\lambda_N^4}\left(\frac{\Delta N}{N}\right)^2 T^2 \lambda r \left[1 - \Phi\left(\frac{2\pi L}{\lambda}\psi_0\right)\right] \exp\left(-\frac{8\pi^2 T^2}{\lambda^2}\right).$$

Here, σ is the backscattering coefficient with respect to power per unit volume; ω is the width of the scattering volume; p is pulse length in meters (1500 meters); N is mean electron density in the scattering volume v during reflections, according to data of vertical sounding; λ_N is the critical wavelength for the mean electron density in the scattering volume; T is the mean dimension of inhomogeneities across the lines of force of the geomagnetic field in meters; L is the dimension of these inhomogeneities along the lines of force; r is slant range in meters; ψ_0 is the angle between the direction of the front of the incident wave and the line of force of the magnetic field at the point of scattering; Φ is the probability integral.

Use of this formula leads to values of T from 0.5 to 3 meters with the most frequent value being T = 1 meter. The mean value of L was estimated on the basis of averaged observed dependences of the amplitudes of radio reflections on ψ_0. It is close to 10 meters.

The magnitude of fluctuation in electron density $\Delta N/N$ sometimes reached 10 percent, but more frequently did not exceed 1-2 percent.

These results are of a preliminary nature and will be made more precise after statistical processing of the data accumulated during the IGY.

ABSTRACT

Studies of 4- and 6-meter radio reflections from aurorae were conducted on Dickson Island by means of plan position indicators. Groups of scattering regions were found to lie along an arc-like line, up to 300-400 kilometers long and apparently less than 20 kilometers wide. Eastward and westward drift of the scattering regions was observed at velocities up to 1000 meters per second.

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III. SOME RESULTS OF THE PROCESSING OF ELECTROPHOTOMETRIC OBSERVATIONS OF AIRGLOW

by A. V. Mironov

During the IGY, electrophotometric observations of primary emissions of the night sky were conducted in the Soviet Union: (OI) (5577 Å), NaI (5893 Å), (OI) (6300 Å). The most complete and systematic observations were conducted at the following points: the Abastumani Astrophysical Observatory of the Academy of Sciences Georgian SSR (Director, L. M. Fishkova), the Crimean Astrophysical Observatory of the AN (Akademiya Nauk -- Academy of Sciences) USSR (Director, K. K. Chuvayev), and the Zvenigorod Scientific Station of the Institute of Atmospheric Physics of the AN USSR (Director, V. M. Morozov).

Non-standard electrophotometers were used with separation of individual regions of the spectrum by means of interference light filters. (A detailed description of the photometer of the Abastumani Observatory and some results of observations are given in references 1, 2.) The light filters for the different emissions varied between 100 and 150 Å in the effective width of their transmission bands and between 15 and 70 percent in their transmission factor.

Observations were conducted in accordance with Roach's instructions (Ref. 3), adopted for the entire international network of stations carrying out the program of electrophotometry of the night sky during the IGY. According to these instructions, on cloudless and moonless nights the brightness at the zenith was measured at the beginning of each hour of zone time in the following spectral regions: about 5300, 5577, 5893, and 6300 Å. In addition, at the Abastumani Observatory emissions near 6050 and 9000-10,500 Å were also observed. The measurements in the 5300 and 6050 Å spectral regions were made in order to determine the magnitude of the continuous background in the night-sky spectrum.

The data obtained were also processed according to Roach's instructions. To determine the intensity of emission lines, the emission of the background was excluded by means of calculating the magnitude of the continuous background in a filter of about 5300 Å, with recalculation for the region of the emission lines according to the brightness curve of a class G2 star. At the Abastumani Observatory, the continuous background was calculated for the 5893 and 6300 Å emissions from measurements in the 6050 Å region.

Thus, from electrophotometry of the night sky at the above-mentioned points we have data on the following: the emission of the continuous background about 5300 Å, the emissions of atomic oxygen at 5577 and 6300 Å, and the emission of sodium at 5893 Å. In addition, as we have already mentioned, there are data from the Abastumani Observatory on the emission of the continuous background near 6050 Å and on emission in the spectral region of 9000-10,500 Å, which is taken to be the overall intensity of the OH emission bands observed in this region. The OH bands (8.4), (3.0), (9.5), and (4.1) are located in 9000-10,500 Å region and fill almost the entire interval of wavelengths. According to the observations reported in references (4, 5), these are extremely intense bands of OH emission. It must be noted that the continuous background was not accounted for in interpreting the electrophotometric measurements of the OH bands with a filter for the 9000-10,500 Å region.

The quantity of material obtained during the IGY varies and is not evenly distributed over the different months. In certain months there were no measurements at all because of cloudiness. In addition, for the Zvenigorod Station the summer months (May-August) were excluded from the period of observations because the declination of the sun does not reach 18 degrees during this time.

Figure 1 shows graphs of the annual course of the various emissions at each station. As is evident from the graphs, the emission of the continuous background near 5300 Å, according to the data from the stations at Abastumani and Simferopol' changes very little during the year and is of a relatively small magnitude. For Abastumani the mean monthly value of the background emission is about one Rayleigh per angstrom, while for Simferopol' it is between 0.5 and 0.7 Rayleigh per angstrom. According to the data from the Zvenigorod Station, the annual variation in the emission of the continuous background near 5300 Å is more significant, and the magnitude of this emission is greater, varying between 1 and 2 Rayleighs per angstrom. The emission from the continuous background near 6050 Å, according to the data from Abastumani, has an

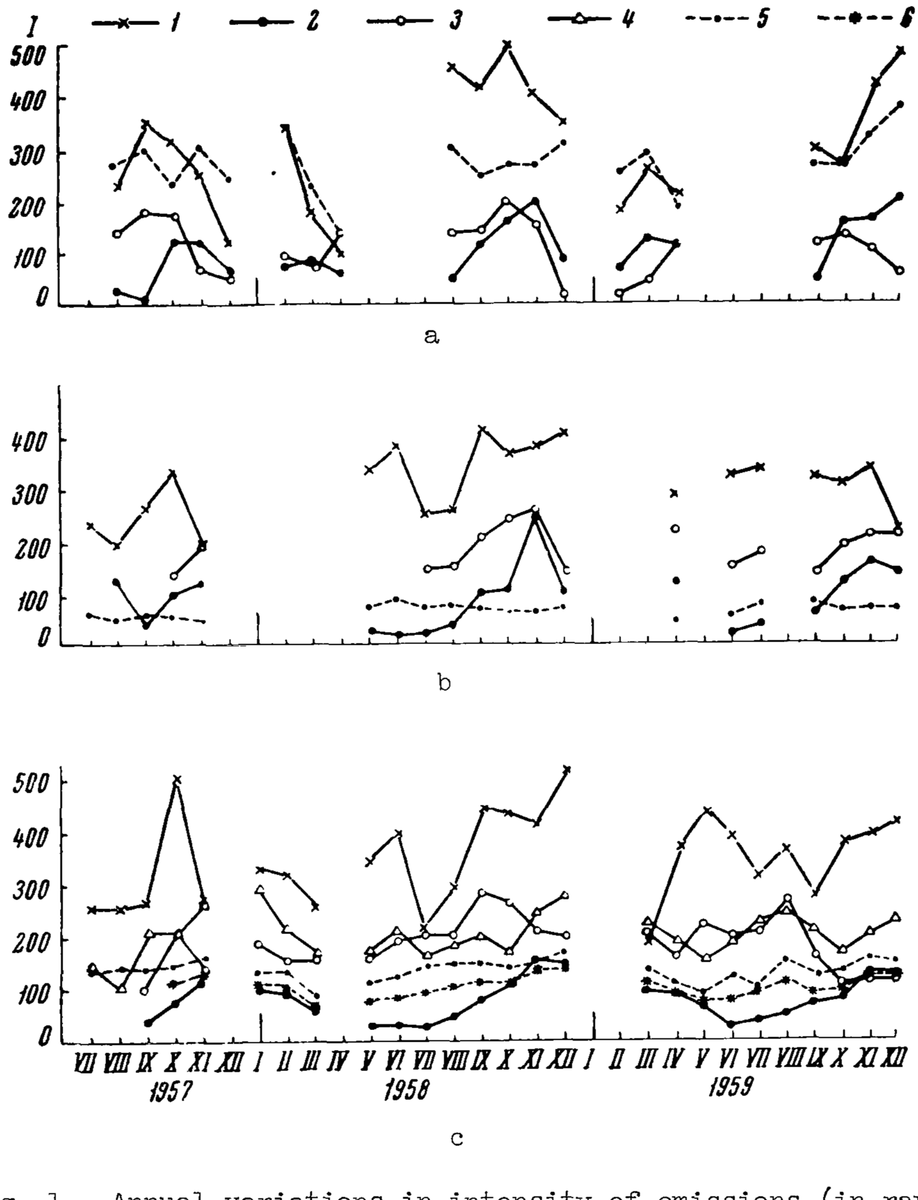

Fig. 1. Annual variations in intensity of emissions (in rayleighs) at Zvenigorod (a), Simferopol' (b), and Abastumani (c).

1 = 5577 Å; 2 = 5893 Å; 3 = 6300 Å;

4 = OH; 5 = 5300 Å; 6 = 6050 Å .

even annual course which is almost parallel to the course of the emission near 5300 Å. The magnitude of the background in this region varies from 0.5 to 1 Rayleigh per angstrom. The (OI) emission at 5577 Å, according to the data of all the stations, has a very uneven course with a not clearly defined maximum of intensity in the autumn. The 5577 Å emission exceeds the others considerably in intensity. For Abastumani, the NaI emission at 5893 Å has a smooth annual variation with a fall-winter maximum and a summer minimum. Maximum intensity is 5-7 times as great as minimum intensity. The minimum mean monthly intensity is about 20 Rayleighs. For the other stations, the annual variation of the Na emission has a comparatively sharp maximum during October-December. The minimum mean monthly value of the intensity of the Na line for Simferopol' and Zvenigorod is about 10 Rayleighs and the maximum is about 200 Rayleighs. The (OI) emission at 6300 Å does not have a characteristic annual variation, although there is a small autumnal maximum observed at all the stations. Hydroxyl emission in the 9000-10,500 Å region (according to data from Abastumani) apparently has a small winter maximum (lack of data for December 1958 and January and February 1959 make it impossible to trace the course of this emission reliably during the winter).

The nocturnal variation of all of the emissions, as shown by analysis of the curves for the entire period of observation, is extremely diverse. All of the observational material was divided into five groups according to the character of the nocturnal variation of the individual emissions. The observational material from the stations, thus classified according to the character of the nocturnal variation of the individual emissions, is shown in the table, where the number of cases of similar variation is expressed as a percentage of the total number of observations. From the table it can be seen that the intensities of the emissions from the continuous background near 5300 and 6050 Å do not vary during the night in a considerable number of cases (from 50 to 80 percent). The (OI) emission at 5577 Å has a maximum during the night in only up to 40 percent of the cases and a minimum in about 10 percent of the cases. The (OI) emission at 6300 Å has a nocturnal minimum in 50-70 percent of the cases, a different course being found in a small number of cases. The Na emission has primarily an even intensity during the night; in the 9000-10,500 Å region a nocturnal maximum is found in 20 percent of the cases and occurs during the second half of the night. Examples of the nocturnal course of the emissions are shown in Figure 2.

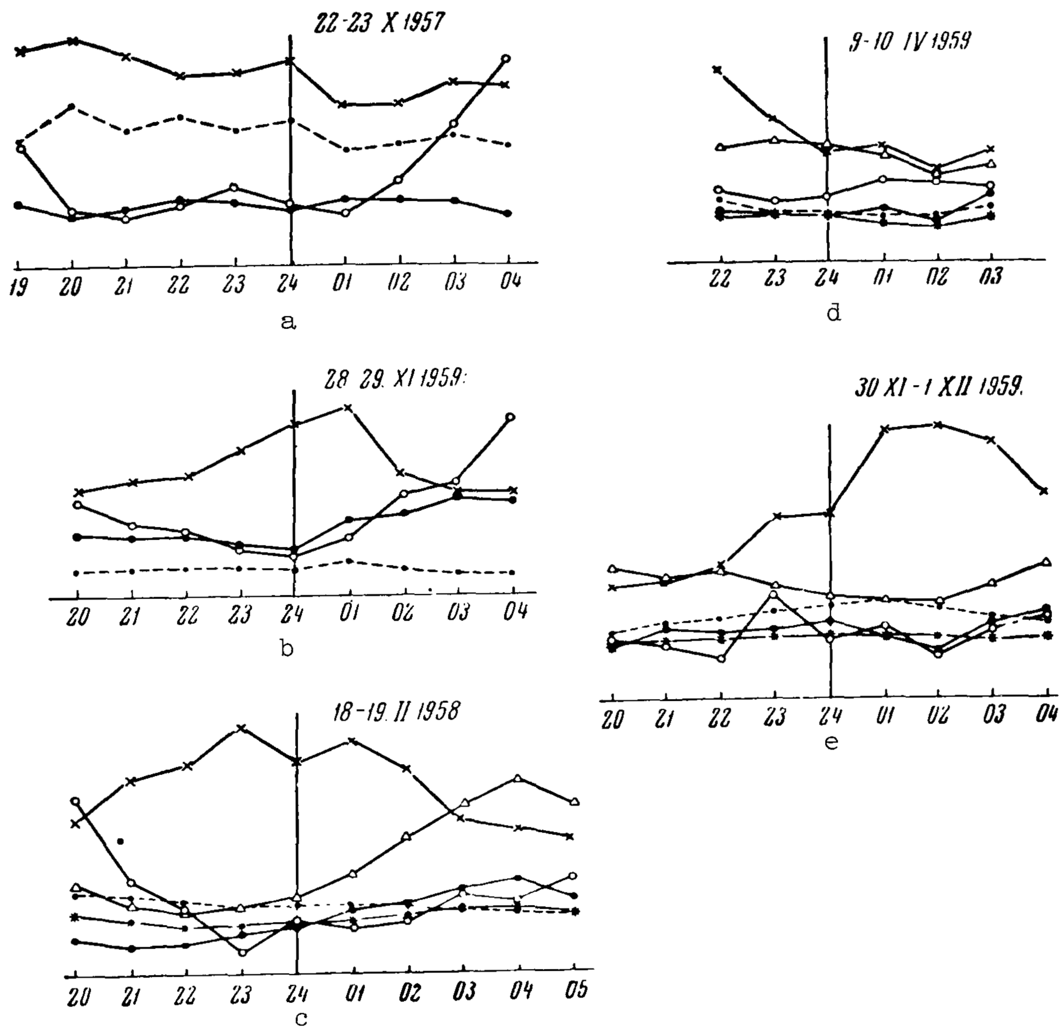

Fig. 2. Examples of nocturnal variations of emission intensities. Local time: a - Zvenigorod; b - Simferopol'; c,d,e - Abastumani. Arbitrary symbols are the same as in Fig. 1.

Repetition of Nocturnal Variation of Intensities
of Various Emissions as a Percentage
of the Total Number of Observations

	Near λ 5300 Å					λ 5577 Å					λ 5893 Å				
	∧	—	╱	╲	∨	∧	—	╱	╲	∨	∧	—	╱	╲	∨
Zvenigorod	14	51	11	24	0	29	16	13	29	13	13	49	7	13	18
Simferopol'	12	82	5	1	0	36	18	20	15	11	4	61	13	9	13
Abastumani	19	46	25	8	2	42	14	14	18	12	26	44	24	3	3

	λ 6300 Å					Near λ 6050 Å					λ 9000–10 500 Å				
	∧	—	╱	╲	∨	∧	—	╱	╲	∨	∧	—	╱	╲	∨
Zvenigorod	9	13	2	18	58	—	—	—	—	—	—	—	—	—	—
Simferopol'	0	8	3	23	66	—	—	—	—	—	—	—	—	—	—
Abastumani	5	22	2	19	52	10	74	10	6	0	17	34	17	21	11

Arbitrary Symbols:
- ∧ maximum in intensity during night
- — even intensity during night
- ╱ rising intensity during night
- ╲ falling intensity during night
- ∨ minimum in intensity during night

Note: The table includes observations from nights in which not less than four cycles of measurements were made: 55 nights for Zvenigorod, 85 nights for Simferopol', 61 nights for Abastumani.

Comparison of the intensities of the individual emissions, as measured at all three stations during the IGY, shows that there is no correlation between the intensity of emission from the continuous background near 5300 Å and that of the green line at 5577 Å. There is no correlation between I_{5577} and I_{5890} or between I_{5577} and I_{6300} (with the exception of Zvenigorod, where there is a correlation between I_{5577} and I_{6300}). The Na I_{5890} emission, according to the data from Abastumani and Simferopol', does not correlate with the I_{6300} emission. According to the Abastumani data, there is a good correlation between the I_{5300} and I_{6050} emissions of the continuous background and a weak correlation between I_{5300} and I_{OH}. There is a weak correlation between I_{6050} and I_{OH}. There is correlation between I_{5890} and I_{6050} and between I_{5890} and I_{OH}. There is no correlation between I_{6050} and I_{6300} or between I_{6300} and I_{OH}. It should be noted that the same comparisons based on figures from which the background has not been subtracted show a better correlation between the emissions. This is related to the fact that emissions from the continuous background in the various spectral regions correlate well with one another. Consequently, in processing the results of electrophotometric observations, account for the background is for the most part correct.

Our result does not agree with the data of Barbier (Ref. 6) and Tohmatsu (Ref. 7), who found a good correlation between the emission of the continuous background and that of (OI) at 5577 Å. Earlier, Barbier (Ref. 8) observed a correlation between the Na emission and the (OI) emission at 6300 Å as well, although in a later article (Ref. 6) he expressed doubt on this point.

Comparison of the electrophotometric data just discussed with the results of spectrographic observations of night sky emissions carried out by Prokudina (Ref. 9) shows that there is no correlation between the (OI)5577 Å and OH emissions or between the Na and (OI) 6364 Å emissions with either of the methods of investigation. The electrophotographic and spectrographic results also agree in another case: they show a correlation between the Na and OH emissions (it must be noted that the OH emission dealt with in (Ref. 9) was measured in a different spectral region).

ABSTRACT

Annual and nocturnal variations of night-sky emissions are analyzed according to data from electrophotometric observations performed in the Soviet Union during the period of the IGY. The results of a comparison of the intensities of the different emissions are given.

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IV. OH EMISSION ACCORDING TO OBSERVATIONS AT ABASTUMANI

by L. M. Fishkova and G. V. Markova

During the IGY, spectra of the night airglow were investigated at Abastumani ($\Phi = 36.7^{\circ}$, $\Lambda = 120.3^{\circ}$) by means of the powerful SP-48 spectrograph, which is described in references (1, 2). In this article are presented results of the processing of about 40 spectrograms showing the OH emission in the 6100-6700 Å region. The spectrograms were obtained on perfectly clear nights; in the processing we took account of the spectral transparency of the atmosphere, which was determined during the course of each observation night according to the method described in reference (3). Observations were made in the direction of north at a zenith angle of $z = 67^{\circ}$.

The rotational temperature of the OH bands was determined according to the (9.3) band for the P branches, using the formulas given in reference (4), and then was reduced to the temperatures obtained from the formulas of Hill and van Vleck by means of the transparency factor given in reference (5).

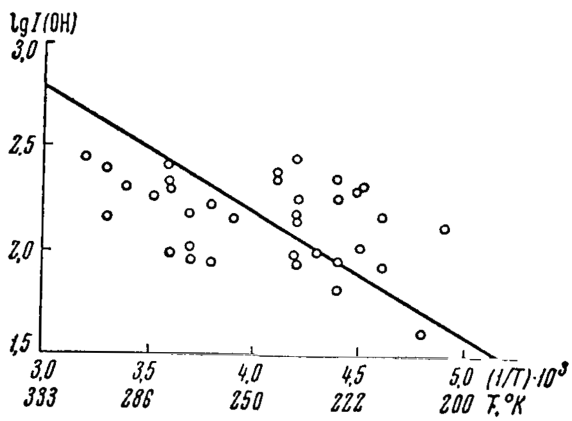

Fig. 1. Relation between intensity of OH (9.3) band and rotational temperature.

Figure 1 shows the dependence of the logarithm of the total intensity of the OH (9.3) band on the magnitude of 1/T. This dependence, obtained by Yarin (Refs. 6, 7) in Yakutsk, which corresponds to an ozone-hydrogen reaction with an activation energy of 2.7 kcal/mole, is shown by the solid line. As is evident from Figure 1, at Abastumani the intensity of the OH bands possibly depends on temperature only at high temperatures ($T > 250^{o}K$) and not at low temperatures ($T < 250^{o}K$). Here we must remember that the points with $T > 250^{o}$ K pertain to January, February, November, and December 1958 and September 1959, while the points with $T < 250^{o}$ K pertain to the summer months.

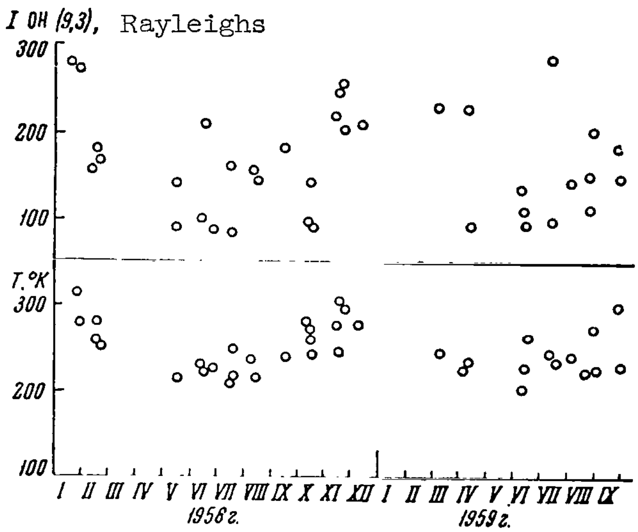

Fig. 2. Seasonal variations in intensity and rotational temperature of OH band.

Figure 2 shows the annual variation in the intensity of the OH (9.3) band and in the OH rotational temperature for the period from January 1958 through September 1959. Both the intensity of the OH bands and the OH rotational temperature show considerable variation from night to night and, on the average, have identical annual variations with a maximum in November-December. The relative spread of points for the rotational temperature is less than that for the intensity of the OH bands. The rotational temperature has a distinct maximum in the winter and minimum in the summer. The OH band intensity, which yearly reaches its greatest maximum in November-December, may also have a lesser maximum in the summer that is not repeated every year (Ref. 8) The summer flares of OH band intensity are not accompanied by an increase in the rotational temperature.

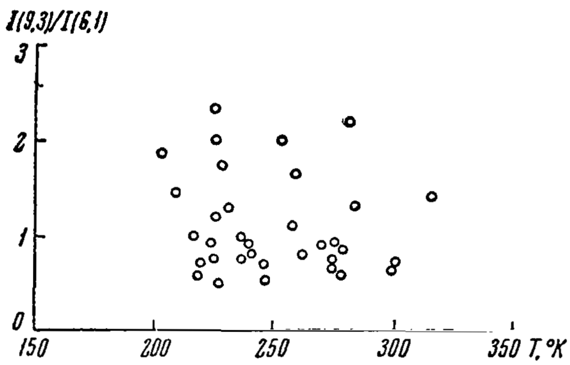

Fig. 3. Relation between ratio of (9.3) and (6.1) band intensities and rotational temperature.

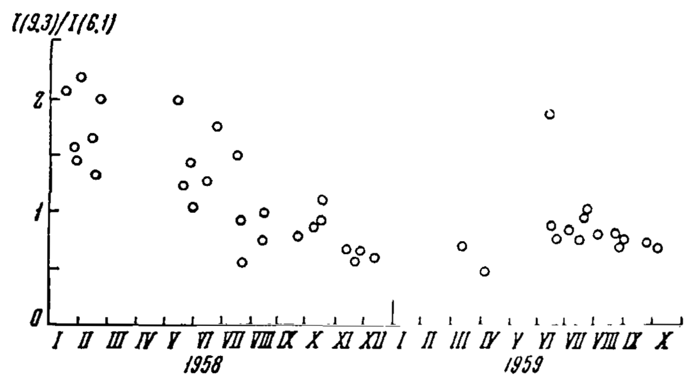

Fig. 4. Seasonal variations in the ratio between the intensities of the (9.3) and (6.1) bands.

The mean OH rotational temperature for Abastumani from January 1958 through September 1959 was 225 $\pm$ 10° K, and the mean intensity of the OH (9.3) band was 160 Rayleighs.

The dependence of the ratio between the intensities of the (9.3) and (6.1) bands on rotational temperature was studied. According to our observations, this dependence is absent (Figure 3). Independently of how the rotational temperature changed during the period under study, the ratio of the intensities of the (9.3) and (6.1) bands decreased steadily from 2-1.5 at the beginning of 1958 to 1-0.6 in September 1959 (Figure 4).

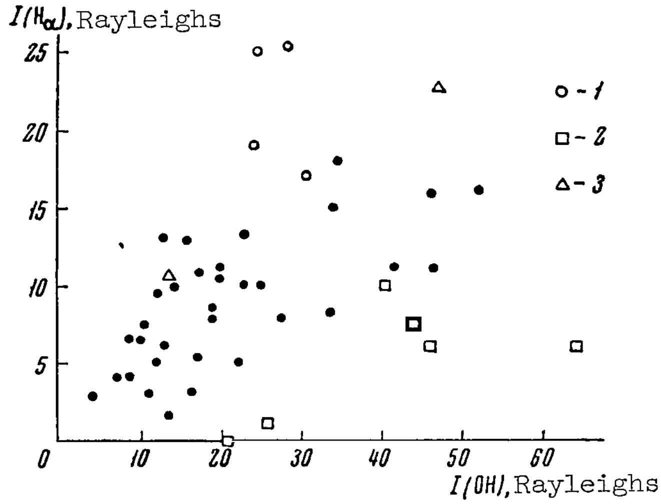

Fig. 5. Relation between the intensities of the H_α and OH P_2 (6.1) emissions:

1 - observations during period of H_α maximum;

2 - observations during period of OH maximum;

3 - observations in which the Milky Way was in the field of view of the spectrograph.

Fig. 5 shows the relation between the intensities of the H_α and OH P_2 (6.1) emissions. It was noted that the intensity of the H_α emission has a seasonal variation with a maximum in July (Ref. 9), while the intensity of the OH emission is maximum in November-December. If we exclude the specially designated points in Fig. 5 (see the symbols in the figure), the relation between the intensities of the H_α and OH P_2 (6.1) appears distinctly: increase in one is accompanied by increase in the other. This coincides with results obtained at Zvenigorod (Ref. 10) and Yakutsk (Refs. 6, 11).

ABSTRACT

Results of observations of the emission bands and rotational temperature of hydroxyl at Abastumani from January 1958 through September 1959 are presented. Seasonal variations of OH rotational temperature have their maximum in winter and their minimum in summer, the mean value being $225 \pm 10^\circ$ K. There is probably some dependence of OH band intensity on rotational temperature for $T > 250^\circ$ K. The ratio of the intensities of the (9.3) and (6.1) bands does not depend on T; this ratio decreased steadily during the period of observations. A relation is observed between the H_α 6562 Å and OH P_2 (6.1) emission intensities.

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V. POPULATIONS OF HYDROXYL MOLECULE VIBRATIONAL LEVELS

by N. N. Shefov

Systematic observations of OH emission have been conducted at the Zvenigorod Station of the IFA AN SSSR (Institut Fiziki Atmosfery Akademii Nauk SSSR -- Institute of Atmospheric Physics of the Academy of Sciences USSR). Earlier, the absolute intensities of the OH bands in the spectral region of 5,200-12,500 Å were determined. Later, with the accumulation of data these intensities were made somewhat more precise.

On the basis even of the initially measured intensities, one could conclude that the lower vibrational levels have a much greater population than is the case with hydroxyl molecules which have been excited only to the ninth level (Refs. 1, 2). In addition, the observations at Zvenigorod do not show a relationship between the intensity of the OH (9.3) band and rotational temperature, although isolated cases were observed in which there was increased intensity at high rotational temperature (Refs. 3, 4). This is also evidence of a greater population in the lower vibrational levels if we consider the mechanisms of formation of excited hydroxyl molecules -- as a result of ozone-hydrogen (Refs. 5, 6) and oxygen-hydrogen (Refs. 7, 8) reactions.

For a qualitative evaluation of the populations of the various vibrational levels we plotted, using the Zvenigorod data, the logarithms of the OH band intensities against the energies $G(v)$ of the corresponding initial vibrational levels (Figure 1). The points indicate the measured band intensities in Rayleighs. The lines show the distributions of intensity in increments Δv = const, which were plotted from the transition probabilities for a linear dipole moment (Refs. 9, 10, 11) in such a way that they best satisfied the experimental values. As is evident, the measured ratios of OH band intensities from the common upper level are in good agreement with the theoretical calculations. However, inasmuch as the linear representation of a dipole moment is only a first approximation, it is possible that noticeable deviations of calculated values from observed values may be detected for transitions with small Δv. Using the correlations between band intensities for $\Delta v = 2$ from the data of Harrison and Jones (Ref. 12), Moroz (Refs. 13, 14), Connes and Gush (Ref. 15), and also the data in Figure 1, the intensities of all OH bands with initial vibrational levels from the third to the ninth were calculated. For this the transition probabilities for a linear dipole moment were used. The results of these calculations are given in Table 1. For comparison, Table 1 also shows the absolute intensities of the OH

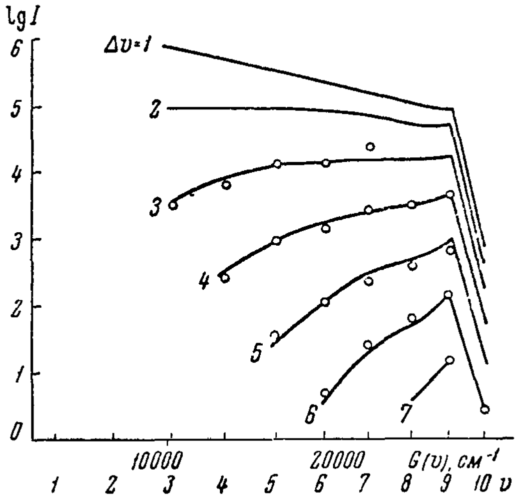

Fig. 1. Relation of the logarithms of OH band intensities to energy G(v) of the corresponding initial vibrational levels. Points indicate measured intensities (in Rayleighs).

bands as measured by other authors. Wavelengths λ_{atm} and wave numbers ν_{vac} at the beginning of the bands are taken from reference (16). For the OH bands from the ninth level the values of λ_{atm} and ν_{vac} were calculated from the formula derived by Chamberlain and Roesler (Ref. 17). For the (10.5) band the value of ν_{vac} differs by 8 cm^{-1} from that given by Kraus (Ref. 18).

Beginning of Band			Measured Intensities in Rayleighs										
v', v"	λ_{atm} Å	ν_{vac} cm-1	Onaka and Nakamura (Ref. 19)	Harrison and Jones (Ref. 12)	Dufay (Ref. 20)	Fedorova (Refs. 21, 22)	Moroz (Refs. 13, 14)	Kvifte (Ref. 23)	Fishkova and Markova (Refs. 24, 25, 26)	Blackwell, Ingham, and Rundle (Ref. 27)	Yarin (Refs. 4, 28)	Shefov (Refs. 3, 4)	Calculated Intensities in Rayleighs
10,0	3539,4	28245,3											0,0001
9,0	3816,6	26193,9											0,03
10,1	4051,5	24675,6											0,003
8,0	4172,9	23957,5											0,1
9,1	4418,8	22624,3											0,9
7,0	4640,6	21543,2											0,6
10,2	4699,8	21271,7											0,04
8,1	4903,5	20387,9								4			3
9,2	5201,4	19220,3								1	10	15	14
6,0	5273,3	18958,2								1	10	5	4
10,3	5544,4	18031,4											0,4
7,1	5562,2	17973,6								4	20	25	20
8,2	5886,3	16983,9						75		31	65	60	60
5,0	6168,6	16206,7						30		11	30	35	35
9,3	6256,0	15980,1						160	160	81	120	140	140
6,1	6496,5	15388,6						100			90	110	120
10,4	6685,4	14953,8										3	3
7,2	6861,7	14569,6										220	280
8,3	7274,5	13743,7			450							400	460
4,0	7521,5	13291,5			300							250	300
9,4	7748,3	12902,4			600							600	890
5,1	7911,0	12637,1			1000							900	930
10,5	8304,4	12038,5											16
6,2	8341,7	11984,6			1600	1 700						1 300	1 700
7,3	8824,1	11329,4	2500		2700	2 800					2100	2 500	2 500

8,4	9373,0	10666,0			1900	3 300			19 400		3000	3 000	3 000
3,0	9788,0	10213,8			3300	1 400					2500	3 500	3 900
9,5	10110,1	9987,2			4100	3 700					4000	4 500	4 500
4,1	10273,3	9721,9			8600	8 000					5300	6 000	8 000
10,6	10764,7	9287,1											65
5,2	10827,7	9233,1				12 000						12 000	12 000
6,3	11432,8	8744,4										15 000	14 000
7,4	12115,4	8251,7										22 000	15 000
8,5	12898,4	7750,8					50 000						14 000
9,6	13816,7	7235,7											16 000
2,0	14335,9	6973,6											
10,7	14916,7	6702,1											200
3,1	15046,6	6644,2					55 000						92 000
4,2	15823,7	6317,9		175 000			60 000						93 000
5,3	16681,9	5992,9					50 000						90 000
6,4	17642,2	5666,7											77 000
7,5	18733,8	5336,5											63 000
8,6	19997,3	4999,3											48 000
9,7	21496,3	4650,7					5 000						47 000
10,8	23315,7	4287,8											450
1,0	28006,7	3569,6											
2,1	29369,2	3404,0											
3,2	30853,9	3240,2											800 000
4,3	32482,9	3077,7											520 000
5,4	34293,6	2915,2											360 000
6,5	36333,9	2751,5											240 000
7,6	38674,2	2585,0											160 000
8,7	41408,6	2414,3											97 000
9,8	44702,5	2236,4											82 000
10,9	48734,6	2051,4											700

Table 1.

Absolute Intensities of OH Bands According to Measurements by Various Authors

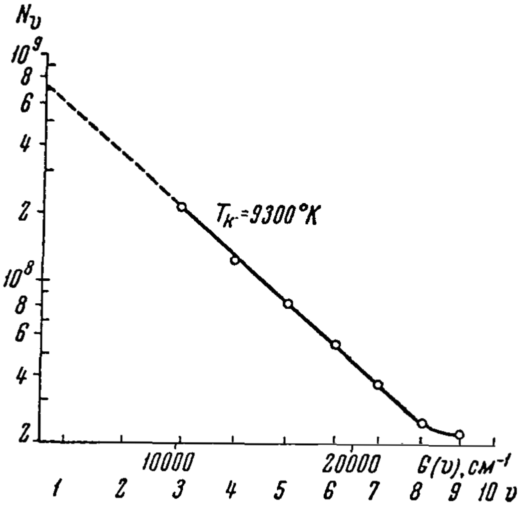

Fig. 2. Distribution of populations N_ν of OH molecules over vibrational levels. The point for the tenth level cannot be shown on this graph with the scale chosen for the ordinate axis.

v'	N_v	F_v	N_v	F_v	N_v/N_9	F_v/F_9
	cm^{-2} (Shklovskiy)		cm^{-2} (Heaps, Herzberg)			
3	$2,3\cdot10^8$	$6,7\cdot10^7$	$3,5\cdot10^9$	$1,0\cdot10^9$	10	2,9
4	$1,3\cdot10^8$	$3,5\cdot10^7$	$2,0\cdot10^9$	$5,3\cdot10^8$	5,7	1,5
5	$8,8\cdot10^7$	$2,6\cdot10^7$	$1,3\cdot10^9$	$3,9\cdot10^8$	3,7	1,1
6	$5,6\cdot10^7$	$1,9\cdot10^7$	$8,5\cdot10^8$	$2,8\cdot10^8$	2,4	0,8
7	$3,9\cdot10^7$	$1,5\cdot10^7$	$5,8\cdot10^8$	$2,3\cdot10^8$	1,7	0,66
8	$2,5\cdot10^7$	$1,2\cdot10^7$	$3,8\cdot10^8$	$1,9\cdot10^8$	1,1	0,54
9	$2,3\cdot10^7$	$2,3\cdot10^7$	$3,5\cdot10^8$	$3,5\cdot10^8$	1,0	1,0
10	$2,3\cdot10^5$	$2,3\cdot10^5$	$3,5\cdot10^6$	$3,5\cdot10^6$	0,01	0,01

Table 2.

Magnitudes of N_v and F_v calculated from the absolute values of the transition probabilities according to Shklovskiy (Refs. 9,10) and Heaps and Herzberg (Ref. 11).

Figure 2 shows the hydroxyl molecule population distribution N_ν over the vibrational levels of the ground state, as calculated from the OH band intensities listed in Table 1 with use of the absolute transition probabilities given by Shklovskiy (Refs. 9, 10). For comparison we give in Table 2 the populations obtained from the absolute values of the probabilities as given not only by Shklovskiy, but also by Heaps and Herzberg (Ref. 11) for the case of a linear dipole moment. The distribution of populations over the vibrational levels from three to eight thus obtained is represented very well by a Boltzmann distribution. The vibrational temperature T_k corresponding to this distribution is 9300 ± 100° K. These results are in good agreement with those of other authors. From the data of Fedorova (Ref. 22) the value of T_k = 10,500° K is obtained; the calculations of Chamberlain and Smith (Ref. 16) give T_k = 10,000° K. The deviation from a straight line in Figure 2 is observed only for the ninth and tenth vibrational levels. According to Fedorova's data, a similar increase in the population of the ninth level is absent. This, however, is apparently connected with the somewhat lower value of the OH (9.5) band intensity as compared with the Zvenigorod data and the results of other investigators (Refs. 4, 20, 28). Perhaps this is explained by a lower relative population of the ninth level at lower latitudes (Byurakan), inasmuch as according to the observations of Fishkova and Markova (Ref. 26) at Abastumani, there is no relation between intensity and rotational temperature at least for $T < 250°$ K, which corresponds to the range of rotational temperatures observed by Fedorova (Refs. 22, 29). In addition to this, the dispersion of the ratios of the OH (9.3) and (6.1) band intensities is much greater in the Abastumani observations than in the Zvenigorod data (Refs. 3, 4).

Knowing the intensities of all the OH bands, one can also determine the quantity of molecules entering some vibrational level F_ν(OH) apart from cascade transitions from higher levels, i.e., the number of newly formed excited molecules. The distribution of F_ν(OH) over the vibrational levels is shown in Figure 3. The absolute values of F_ν(OH) correspond to the absolute values of N_ν in Figure 2. It is obvious that the assumption of an equal influx of molecules to all vibrational levels is not in agreement with the data in Figure 3. This has already been mentioned in references (4, 30) on the basis of an observed relation between the intensities of OH bands with different initial vibrational levels and rotational temperature (Refs. 3, 4, 26, 28). From Figure 3

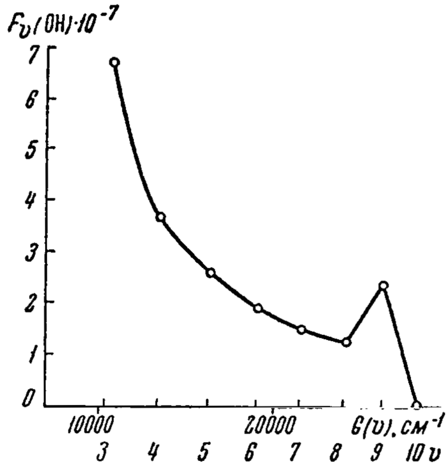

Fig. 3. Distribution over vibrational levels of newly formed excited hydroxyl molecules $F_v(OH)$.

it is also evident that hydroxyl molecules are excited mainly to the lower vibrational levels. The fraction of molecules entering the ninth level is small.

From this it follows that the formation of excited OH molecules apparently takes place simultaneously both in the process of an ozone-hydrogen reaction and in that of an oxygen-hydrogen reaction, the main contribution coming from the latter; inasmuch as, as already has been mentioned, a relation between OH band intensities and rotational temperature has not been detected at Zvenigorod.

The obtained results were compared with data from the laboratory experiments carried out by Kraus (Ref. 18). The distribution of intensities of OH bands with differing and even with the same initial vibrational levels, calculated from Kraus' data for all the mixtures of reacting gases that he used, differs sharply from the distribution in the spectrum of the night airglow represented in Fig. 1. The distribution of hydroxyl molecule populations over the vibrational levels for Kraus' data corresponds to a vibrational temperature of 13,000 $\pm$ 2000 $^{\circ}$ K, whereas the rotational temperature, determined according to the bands observed, is approximately 700° K. Kraus (Ref. 18) asserts that the formation of excited OH molecules under laboratory conditions and also in the upper atmosphere is due to an ozone-hydrogen reaction. Unfortunately, however, the internal contradiction of the values listed by

Kraus (Ref. 18) for the intensities of the OH bands in the 6500-9200 Å region causes a very great spread in the points on graphs, similar to the one shown in Fig. 2, plotted from his data. This prevented determining the quantity of OH molecules excited to the various vibrational levels by the ozone-hydrogen reaction alone, and thus it was not possible to determine, on the basis of the experimental data, the role of the oxygen-hydrogen reaction in populating the vibrational levels.

There is no doubt that it would be very important to conduct new, more careful laboratory studies of the hydroxyl spectrum.

ABSTRACT

On the basis of measured OH band intensities, the populations of the vibrational levels from the third to the tenth are determined. The distribution of newly formed excited OH molecules over the vibrational levels is obtained.

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VI. ON ABSOLUTE PHOTOMETRY OF AURORA AND AIRGLOW SPECTRA

by O. G. Taranova

The absolute intensities of emissions photographically recorded on a spectrograph can be determined with great accuracy by making simultaneous observations with a calibration photometer.

In February-March 1960 such observations were carried out at the Loparskaya Station of IFA AN SSSR (Institut Fiziki Atmosfery Akademii Nauk SSSR -- Institute of Atmospheric Physics of the Academy of Sciences USSR) by N. I. Fedorova and O. T. Yurchenko on SP-48 and SP-50 spectrographs. Simultaneous electrophotometric observations were made with a photometer similar to that described in reference (1). Readings were taken down by an intermittent contact recorder with preamplification as described in reference (2). Constant photometer sensitivity was controlled by an unvarying cesium luminophor in a 5300 Å filter.

Absolute calibration of the electrophotometer was done with respect to the moon (at 5577 Å) on a night with good atmospheric transparency ($\tau_{5577} = 0.24$). A diffusing screen was placed in front of the photometer objective at an angle of 45 degrees to the optical axis. In this way the conditions of calibration were similar to the conditions of observations of the night sky and aurorae. The distribution of energy in the moon's spectrum was constructed according to the known spectral distribution of the sun's energy (Ref. 3) with account taken of the apparent stellar magnitudes of the sun ($m = -26\overset{m}{.}7$) and the moon ($m = -12\overset{m}{.}6$), the spectral albedo of the moon, the correction for phase (Ref. 4), and the transmission curve of the interference filter. (The transmission curve of the interference filter was measured with a UM-2 monochromator in a beam with an entry angle of 5 deg., which is the same as that in the photometer.) This photometer was compared with the standard photometer described in reference (1), which was adapted to the international scale of the Roach photometer. Divergence in the results of absolute photometry from simultaneous measurements with two photometers did not exceed 5 percent.

In order to obtain the intensity distribution of the photographic spectrum in relative units, the spectrograph was calibrated spectrally with the aid of a standard lamp ($T = 2750°$ K) and a magnesium diffusing screen. All photographs of spectra and calibrating photographs were taken on calibrated type A-600 astronomical film at the same temperature of the surroundings.

Two spectral regions were photographed: 10,000-12,000 Å and 4800-6000 Å. Two series of observations were selected for processing: 15-16 March, when there were homogeneous arcs with intensity of about 2 in the field of view of the instruments during exposure, and 30-31 March, when there was an almost quiet night sky.

On 15-16 March the observations were made with the SP-50 spectrograph. The photometer recorded emission from the region of the zenith through a 5577 Å filter. The spectrograph was also aimed at the zenith and photographed simultaneously the emission from OH bands in the 10,000-12,000 Å region in the first order and the green line in the second order. With a two-hour exposure the (9.5), (4.1), and (5.2) bands of OH in the night airglow (Ref. 5) were obtained in the photograph of the spectrum.

On 30-31 March the observations were made with the SP-48 spectrograph. One-half of the spectrograph slit was aimed to the northeast at an angle of 30° to the horizon. The other half of the slit was aimed by means of a prism through a neutral filter toward the zenith to photograph the green line. The photometer recorded the emission from the region of the zenith during the entire period of exposure.

In photometry of the spectra, the intensities of the measured emissions were expressed in wavelength units of 5577 Å. By integrating the area under the curve of the recording of the intensity of 5577 Å according to the electrophotometric observations, we determined the mean (for the exposure time) absolute intensity of the radiation transmitted by the interference filter during observation of the zenith. In processing simultaneous zenith observations (of 15-16 March) of the photometer and the spectrograph, by means of which it is possible to obtain, with high resolution, the energy distribution in the spectrum of the aurora the absolute intensities of the emissions in the photographic spectrum are immediately determined.

From 30-31 March we took a spectrogram at an angle to the horizon; the photometer, as already mentioned, recorded the green line at the zenith. Moreover, the green line on the photograph of this spectrum was overexposed. Therefore, the 5577 Å intensity for this spectrum was taken into account as follows. From the absolute intensity of 5577 Å at the zenith (from electrophotometric data) with consideration of the transparency factor for an altitude of 30° and the variation in the transparency factor with spectral wavelength (Ref. 6), the absolute intensity at 5228 Å was determined for the spectrogram photographed at an angle to the horizon. From references (7, 8) we took the following correlations between the intensities of auroral emissions:

$$I_{3914} : I_{5228} = 30.3,$$

$$I_{5577} : I_{3914} = 0.5.$$

Using these correlations, we find the absolute intensity of 5577 Å in the spectrum photographed at an altitude of 30° from the absolute intensity found for 5228 Å. The intensity of the green line for this case was estimated directly from the intensity of 5577 Å at the zenith with consideration of the transparency factor for an altitude of 30° and the van Rhijn factor. The divergence between the absolute intensities of 5577 Å obtained by these two methods does not exceed 10 percent.

15-16 March		30-31 March					
Q (5.2)	Q (4.1)	λ 5958 Å OI	λ 5890 Å Na	λ 5680 Å N II	λ 5228 Å N_2^+	λ 5200 Å (N I)	λ 5004 Å N II
4100	2900	160	260	50	35	55	20

Table 1
Absolute Intensities of Some Emissions (in Rayleighs)

The transparency factor for 5577 Å was determined according to the method of Bouguer.

The results of determining the absolute intensities by the method described are shown in Table 1.

From the known curve of the transmission of a 5577 Å interference filter and from the portion of the spectrogram from the SP-48 that was analyzed by photometry, which corresponds to the transmission band of the filter, we determined the relative effective emission intensities passing through the interference filter and recorded by the photometer (Table 2).

TABLE 2

Relative Effective Intensities of Some Emissions

Emission	Intensity, percent	Emission	Intensity, percent
λ 5577 (OI)	89	λ 5680 N II	0.3
λ 5632 O_2^+ (1.0)	1.2	Continuum	9.5

ABSTRACT

One of the possible methods of absolute photometry of night-sky and auroral spectra by means of simultaneous observations by spectrograph and calibration photometer is described. Some results of the analysis of such observations are given.

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VII. COMPARISON OF DIURNAL VARIATIONS OF FREQUENCY OF APPEARANCE OF HYDROGEN EMISSION AND RADIO REFLECTIONS ON 72 MEGACYCLES

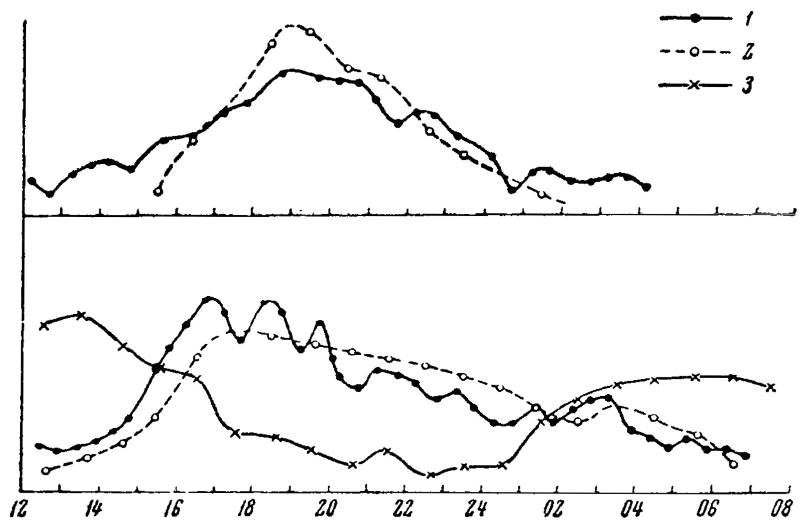
by A. B. Korotin

At the IFA (Institut Fiziki Atmosfery -- Institute of Atmospheric Physics) station in Loparskaya ($\Phi = 63.6^{o}$, $\Lambda = 126.7^{o}$), systematic observations of hydrogen emission were made with an SP-47 patrol spectrograph (Ref. 1). In processing the results, we also used spectra taken by Yevlashin with a C-180-S camera at the Murmansk Branch of the IZMIRAN Institut zemnogo magnetizma, ionosfery i raspostroneniya radiovola AN SSSR (Institute of Terrestrial Magnetism, The Ionosphere, and Radio Wave Propagation of the Academy of Sciences USSR). These stations are separated by about 40 kilometers. During the period under study, hydrogen emission was observed for a total of 123 nights, and the number of spectrograms showing hydrogen emission exceeds 1000. The equipment made it possible to record hydrogen emission with an intensity greater than 200 Rayleighs.

Direct comparison of radio reflections from aurorae with hydrogen emission does not, according to our data, show noticeable correlation between these phenomena. Therefore, in this article we compare the diurnal variation of the appearance of radio reflections on 72 mc with the diurnal variation of appearances of hydrogen emission in auroral spectra. Inasmuch as radio reflections were observed around the clock, the relative number of observed cases of radio reflections in a given hour of the 24 for the period under study was accounted for. Data on radio reflections was taken from the observations by Birfel'd and Grachev at the IFA station in Loparskaya. The radar set is described in reference (2). In plotting the diurnal variation in the frequency of appearance of hydrogen emission, we calculated the ratio of the number of cases of observation of hydrogen emission to the overall number of observations at a given hour of the day. Results of the comparison of these figures are shown in the figure.

The solid line shows the diurnal variation in the frequency of appearance of radio reflections from aurorae; the broken line shows the diurnal variation in the frequency of appearance of hydrogen emission. For comparison the variation curve of the horizontal component of the magnetic field is also shown. In the graph plotted for the winter months (November-February) two closely coinciding maxima are observed, one of which occurs at 17-18 hours world time (magnetic noon), and the other in the morning hours. In the graph plotted for the fall months there is also a correspondence in the diurnal variations; only in this case the main maximum is shifted closer to midnight. Similar diurnal variations are also obtained for the spring months, but the small quantity of experimental data does not permit reliable conclusions as yet. Apparently, the maximum of the curve is shifted toward midnight in the spring too. The diurnal variation in the horizontal component of the magnetic field has a very distinct character. This is discussed in detail in reference (3).

It is also interesting to note that in the winter, radio reflections are not observed in the daytime. Inasmuch as the diurnal variations of radio reflections and hydrogen emission coincide, one may expect that hydrogen emission is not observed in the daytime either.



Comparison of diurnal variations of frequency of appearance of hydrogen emission and radio reflections on 72 mc. The upper graph is for the fall, the lower for the winter. World time:

1 -- radio reflections;
2 -- hydrogen emission;
3 -- horizontal component of magnetic field.

The author is grateful to L. S. Yevlashin, Y. G. Birfel'd, and A. I. Grachev for the opportunity of using the results of their observations in this article.

ABSTRACT

The coincidence of diurnal variations of the frequencies of appearance of auroral hydrogen emissions and auroral radio reflections on 72 mc plotted for the fall and winter months is shown.

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VIII. ON THE RELATION OF INTEGRAL BRIGHTNESS OF AURORAE TO GEOMAGNETIC FIELD VARIATIONS AND SHORT-PERIOD OSCILLATIONS OF EARTH CURRENTS

by A. B. Korotin

Comparisons made by various authors (Refs. 1, 2) show that aurorae, magnetic and ionospheric storms, and earth currents are closely related to each other; an aurora is, as a rule, accompanied by magnetic storms and ionospheric disturbances. However, no exact relation between these phenomena has been detected. In the majority of cases, in these comparisons the brightness of aurorae was measured with photometers or spectrographs having narrow angles of view, which by virtue of the features of their design could not provide full information on the brightness of the aurorae. At the same time it is clear that a magnetic disturbance may be caused by a source located anywhere and having dimensions considerably exceeding the area of the sky usually observed. In view of this, widening the angle of view of the photometer may possibly provide more accurate results or, in any case, show more quickly a direct relation between magnetic field variations and variations in auroral brightness. Murcray (Ref. 3), using a photometer, measured the light flux from the sky scattered by a plane surface but did not detect a close relation between the brightness of aurorae and the activity of earth currents.

For the purpose of comparing variations in the magnetic field and in auroral brightness, a photometer with an angle of view of 180° was prepared at the Loparskaya station. For this, the motion picture apparatus in a C-180 camera was replaced with an FEU-19 photomultiplier. The intensities of the aurorae were measured without filters. The photocurrent was amplified by a DC amplifier and recorded with an N-370 recording instrument. The obtained recordings of variations in auroral intensity $I_{aur.}$ were compared with variations in the horizontal component of the magnetic field H (according to the data from MO (Murmanskoye Otdeleniye - Murmansk Branch) of IZMIRAN) and with the amplitude of short-period oscillations of earth currents (KPK) (according to the data from IFZ AN SSSR (Institut Fiziki Zemli Akademii Nauk SSSR - Institute of Physics of the Earth of the Academy of Sciences USSR) station at Lovozero).

Examples of such comparisons are shown in Figure 1. Comparison of variations in the auroral and magnetic-field intensities makes it possible to establish some correlation between them on the basis of our observations.

1. Even weak flares of auroral brightness are, as a rule, accompanied by a deviation of the magnetic field from its normal state and by an increase in KPK (short-period earth-current oscillation)

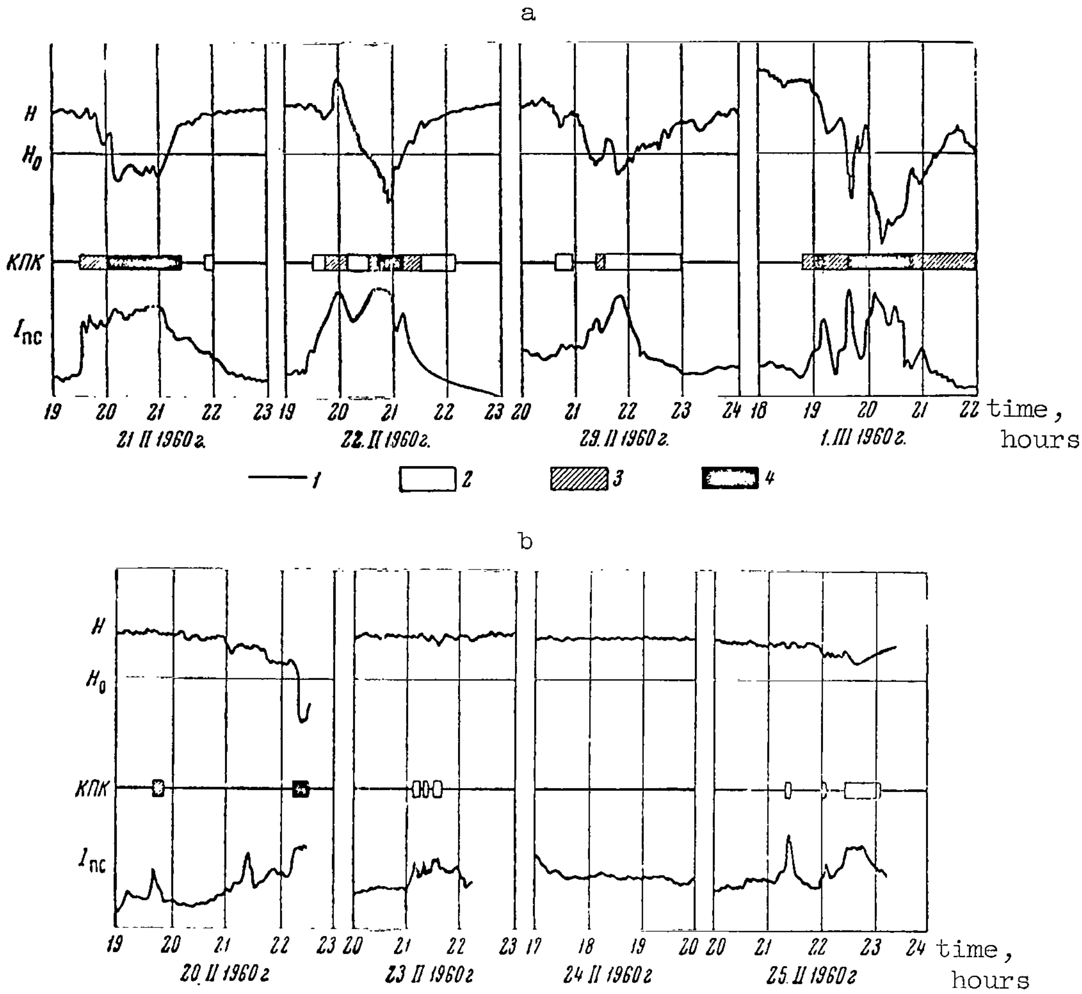

Fig. 1. Comparison of variations in auroral intensity $I_{aur.}$ with variations in the perturbed magnetic field H

(H_0 is the level of the quiet magnetic field). World time.

a - strong disturbance; b - weak disturbance; 1 - no KPK; 2 - weak KPK; 3 - average KPK; 4 - strong KPK.

amplitude.

2. KPK amplitude correlates better with auroral brightness than does the horizontal component of the magnetic field.

3. In the absence of aurorae, the magnetic field is quiet.

4. The relation between auroral brightness and the horizontal component of the magnetic field is also maintained when there is a positive bay of variations in the horizontal component.

5. Within the general relation between the magnetic field and aurorae, individual differences in the courses of these phenomena are observed.

a. While auroral brightness may vary over a wide range in a comparatively short period of time, falling often to the initial level, the horizontal component of the magnetic field increases as rapidly as does auroral brightness, but its return to the initial level is slower. Therefore, if several flares of auroral brightness follow one another after comparatively short intervals, each succeeding flare in the magnetic field starts not at the normal level but at a perturbed level.

b. The greatest deviation of the horizontal component from the normal level is observed several minutes after the maximum brightness of the aurora.

It is known that a change in electron concentration in the ionosphere differs somewhat from the electron formation function (Ref. 2), i.e., there is observed a delay in the ionization maximum and a slower decline in ionization as compared with the course of the electron formation function. A similar phenomenon is also observed for variations in the intensity of an aurora and the magnetic field.

Experimental methods of determining the recombination coefficient have been based on the effects of delay in the maximum and slow decline of ionization. Mitra and Jones give for these cases the following formulas:

$$\alpha = \frac{1-\left(\frac{\Phi_2}{\Phi_1}\right)^2}{N\tau} \qquad (1)$$

for calculating the recombination coefficient from the difference in rates of decay (Ref. 4) and

$$\alpha = \frac{1}{2N_{\tau}} \qquad (2)$$

from the delay in the ionization maximum (Ref. 5). Here, α is the coefficient of recombination, N the electron concentration, τ the delay time, Φ_1 the maximum value of ionization, and Φ_2 the electron concentration at a given moment.

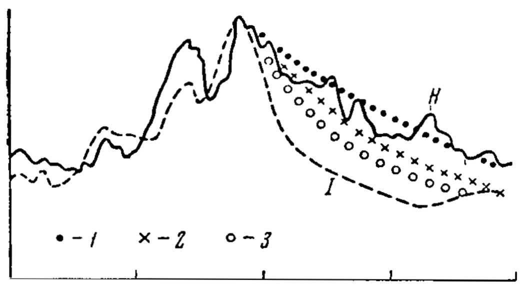

Fig. 2. Comparison of variations in intensity I (broken line) of aurora of 29 February 1960 with the change in the horizontal magnetic field component H (solid line) and with the theoretical variation of ionization:

$1 - \alpha = 0.5 \cdot 10^{-9}$; $2 - \alpha = 1 \cdot 10^{-9}$;

$3 - \alpha = 1.5 \cdot 10^{-9}$.

From the dynamo theory (Ref. 6) it follows that a change in the magnetic field should be related to a change in ionization and a change of wind in the upper atmosphere. However, it may be expected that the wind will not be changing much in a short interval of time. Therefore, let us assume that in the first approximation a change in the magnetic field coincides with a change in ionization. Let us also assume that a variation in auroral intensity reflects a change in the electron formation function. In Figure 2 we show the change in auroral intensity I and the corresponding variation in the horizontal magnetic field component on 29 February 1960. In the same figure we show the theoretical change in ionization calculated from formula (1) for various recombination coefficients (see the arbitrary symbols). Electron concentration N was calculated from the critical frequency for the E_S layer

and was equal to $3.5 \cdot 10^5$ cm^{-3}. From Figure 2 it is evident that the best correspondence between N and H is obtained for

$\alpha = 1 \cdot 10^{-9}$ cm^3/sec. The same result is obtained when the recombination coefficient is calculated from the delay in the ionization maximum.

The recombination coefficient thus obtained is in very good agreement with the theoretical value of α for the E-layer at night. This correspondence is valuable in itself, and also indicates the validity of the assumptions on which the calculation was based.

The small quantity of experimental material does not permit us to draw any final conclusions, although the preferability of the dynamo theory for explaining the results obtained seems obvious.

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ABSTRACT

Results of auroral brightness measurements made at the Loparskaya station (Institute of Atmospheric Physics of the Academy of Sciences USSR) by means of a photometer with a 180° angle of sight are compared with variations in the horizontal component of the geomagnetic field and with short-period oscillations of the earth currents. A clear connection between auroral brightness and variations in the geomagnetic field is confirmed. The differences in the courses of these two phenomena are stated, and an attempt to explain them on the basis of the dynamo theory is made. A connection between auroral brightness and the amplitude of short-period oscillations in the earth currents is stated. An attempt to calculate the recombination coefficient is made.

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IX. ON A POSSIBLE MECHANISM OF GENERATION OF MAGNETIC DISTURBANCES

by A. B. Korotin and M. I. Pudovkin

The interaction of solar corpuscular streams with the earth's atmosphere has up to now been known only in the most general terms. This often makes it necessary to limit one's self to examining a statistical relation between the indexes, instead of a physical analysis of the processes. However, the statistically derived relation between the various indexes of a magnetic-ionospheric storm, which under considerable averaging gives a high coefficient of correlation, becomes worse for individual cases and is sometimes completely lost.

The present article, based on experimental data obtained by the authors at the IFA AN SSSR station in Loparskaya and at the Murmansk Branch of IZMIRAN, presents a study of a rather strong magnetic storm.

As a result of comparing the variations of the geomagnetic field with the intensity of the aurora as measured with a 180-degree photometer (Ref. 1), a very close connection was found between these phenomena in every case of a magnetic disturbance.

Before beginning a detailed analysis of an individual magnetic storm, we shall discuss several of the general features of the course of a magnetic disturbance. As was shown in references (1, 2), a considerable delay is observed (up to 15 minutes) in the maximum of a magnetic disturbance relative to the maximum of auroral brightness. This indicates that magnetic disturbances (at least their long-period portion, which is measured with variometers having a magnetic needle) are closely related to increased ionization in the ionosphere under the action of a primary corpuscular stream, i.e., to increased ionospheric conductivity. This limits considerably the number of processes possibly causing magnetic disturbances. We shall not dwell on the form of the current systems or the magnitude of the current, since these data are discussed in sufficient detail elsewhere, for example in reference (3). It may be expected that processes directly related to the incursion of a corpuscular stream should have similar diurnal variations. However, in averaging a large number of cases, the features connected with a specific aurora are eliminated, if these features do not have their own diurnal variation.

This is illustrated by a figure in reference (4), which shows diurnal variations in the frequency of appearance of radio reflections from aurorae and hydrogen emission on a frequency of 72 mc. The diurnal variations were practically identical in spite of the different origins of these processes and the absence of a direct relation between the presence of hydrogen emission and radio reflections (not more than

40 percent of the cases were coincident). Consequently, this diurnal variation reflects the diurnal variation of an intrusion of a corpuscular stream, and more particularly so since, in the first place, it is difficult to imagine another process that could connect these two phenomena, and, secondly, because hydrogen emission in auroral spectra indicates directly the incursion of a corpuscular stream.

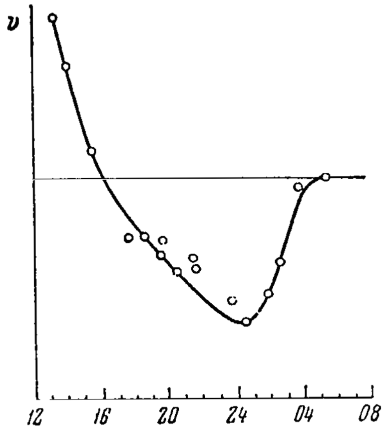

Fig. 1. Diurnal variation of meridional component of ionospheric wind velocity for January-February 1959. World time.

The curves shown in the figure in reference (4) were plotted for the winter period. For comparison, the diurnal variation in the horizontal magnetic field component for the same period is also shown there. The sharp difference between these curves can only be explained by the fact that the magnetic variations and the currents causing them are related not only to the incursion of a corpuscular stream but also to some other process in the upper atmosphere with its own diurnal variation, this displacing the maximum of magnetic activity. The general character of the curve of the diurnal variation of such a process can be evaluated from comparison of the curves described. In Figure 1 we show the diurnal variation of the meridional component of ionospheric wind velocity v, which is directly related to the process of generation of a current in the ionosphere, whereas ionization is related to the diurnal variation of the incursion of a corpuscular stream. To determine the mechanism of current generation, it is necessary to find a process having the diurnal variation shown in Figure 1. For this purpose, let us examine a specific example.

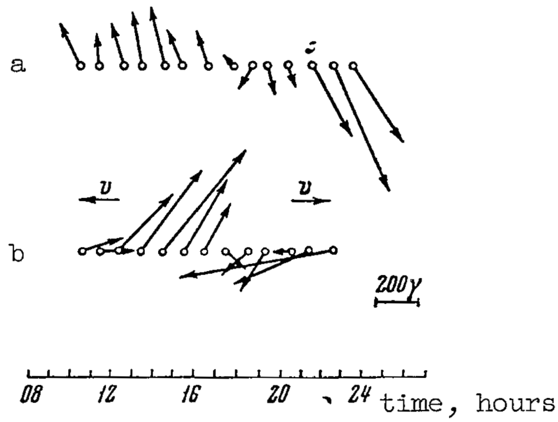

Fig. 2. Diurnal variation of vectors of disturbed magnetic field on 26 March 1959. World time. a - in the horizontal plane; b - in the vertical plane.

Figure 2a shows the diurnal variation in the vector of the horizontal component of the disturbed magnetic field H on 26 February 1959. Attention is drawn to the fact that at 18 hours world time the magnetic disturbances change sign from positive to negative, and for a certain period the disturbance equals zero in spite of the fact that during this time, corpuscular streams are observed with the greatest frequency. The distribution of the vectors in the vertical plane (Figure 2b) shows that the center of gravity of the electric currents causing the magnetic disturbances is moving from north to south until 18 hours, and from south to north after 18 hours. This situation is always observed, and does not depend on the intensity of the storm. Thus, at 18 hours the direction of movement of the entire current system is changed. If we assume that this movement is determined by winds in the ionosphere (Ref. 5), the wind direction in the ionosphere must also change at 18 hours.

Thus, the results of experiments lead to the same initial data as are at the basis of the dynamo theory (Ref. 3) and the observed features are explained most simply and naturally by this theory.

In fact, according to this theory, the intensity of the ionospheric currents equals $\vec{j} = \sigma \, /\vec{\nu}\vec{Z}/$, where σ is the conductivity of the ionosphere, $\vec{\nu}$ is wind speed, and $\vec{Z}$ is the vertical component of the geomagnetic field. In this case σ is proportional to ionization density and should have at night a diurnal variation similar to the diurnal variation of corpuscular stream intensity, while $\vec{\nu}$ has its own diurnal variation, which is not related to stream intensity (Ref. 6).

As a result, the diurnal variation of $\vec{j}$ should differ from that of σ.

In addition, for a rapid change in the magnetic field, the fact that ionization density is determined not only by the magnitude of the recombination coefficient α but also by the ionizing potential of the corpuscular stream becomes important. Thus, a magnetic disturbance is determined by three quantities: the wind speed, rate of ion formation $q(t)$, and recombination coefficient. In this article we attempt to determine these three quantities.

First of all we should mention that the obtained diurnal variation of wind has one peculiarity. From Figure 2a, it is evident that the vector of a magnetic disturbance has a rather constant direction over a 24-hour period independently of the intensity of the magnetic disturbance (30° to the west of magnetic north during the daytime, and 150° to the east of magnetic north at night). Since the direction of the ionospheric winds must change in the course of a 24-hour period, such a constancy in the direction of the vector of a magnetic disturbance is evidence that the regions of corpuscular incursion are greatly elongated in an approximately longitudinal direction. Therefore, only that component of the wind velocity that is perpendicular to the major axis of these regions, i.e., the meridional component, can be determined from magnetic data.

We shall now use these results to examine a rather intense magnetic storm occurring on 1 March 1960, the center of gravity of whose sources was located above our stations. In reference (1) it was shown that changes in the horizontal component of the magnetic field are very closely related to changes in the intensity of auroral emissions as recorded with a 180° photometer. In Figure 3 we show a recording of the change in intensity of the aurora $I_{aur.}$ and of the component of the magnetic field H. As is evident from the figure, the two curves indeed have much in common. However, there are characteristic differences between them which are preserved during other storms as well. Inasmuch as these differences are of great significance in calculation, it is worth repeating them.

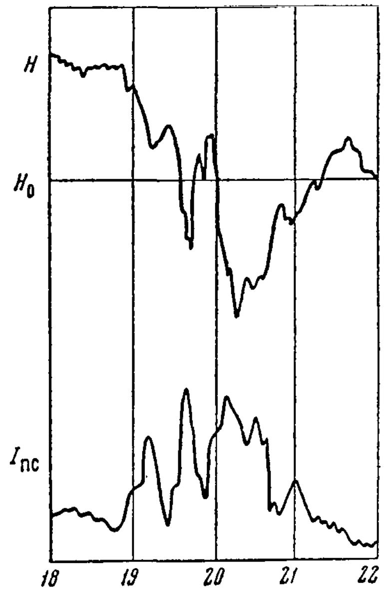

Fig. 3. Comparison of variations of the aurora intensity of $I_{aur.}$ and the component of magnetic field H for 1 March 1960. (H_0 is the level of the quiet field.) World time.

1. The maximum of H lags behind the maximum of I by an average of 5 minutes.

2. The correlation between the amplitudes of individual peaks in H does not coincide with the correlation between the corresponding peaks in I. For example, on the I-curve the second peak is the greatest, while on the H-curve the third peak is the greatest.

3. Between peaks the value of I falls almost to zero, while the decrease in H is much less; at the final stage of the storm, H returns to its normal value noticeably more slowly than does I. These features of the variation in H, as already mentioned in reference (1), are easily explained by a small recombination coefficient.

From the delay of the peaks in H relative to the peaks in auroral intensity and from the differing rates of attenuation of H and I, one of the authors (Ref. 1) evaluated for a number of individual bays the magnitude of the recombination coefficient in the ionosphere at the altitude at which flow the currents that cause magnetic disturbances.

The recombination coefficient turned out equal to $(1\text{-}4)\cdot 10^{-9}$ cm^3/sec. This indicates that the currents causing magnetic storms flow, apparently, in the E-layer. In the case of the storm under study we can, strictly speaking, determine only α N, but proceeding from a number of additional considerations, we can determine α more precisely.

First of all, in comparing H and I, it is necessary to take into account the fact that the change in H is affected by a change in wind speed. It is not known how the wind speed varied during this storm. Therefore, the effect of the wind was calculated from the mean diurnal variation of wind velocity for the appropriate season (see Figure 2).

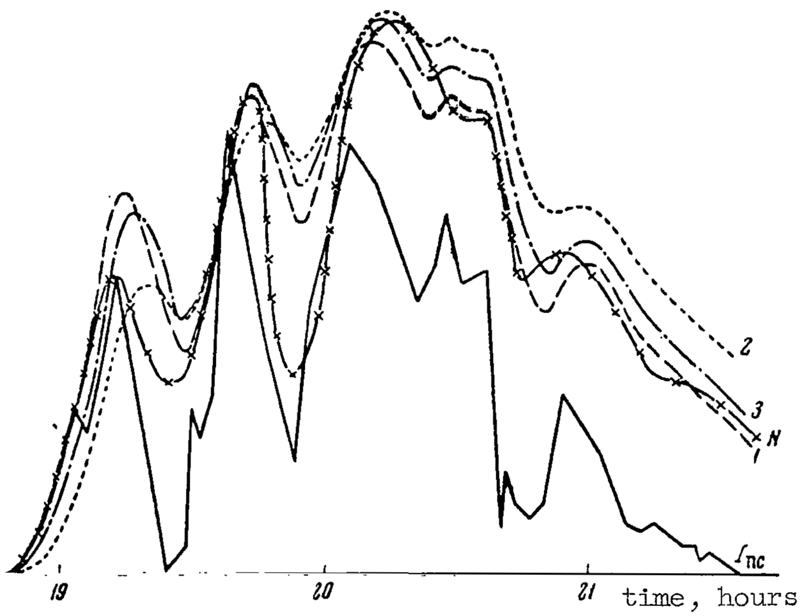

Fig. 4. Comparison of variations of $I_{aur.}$ and calculated changes in ionization density. World time. Symbols are the same as in the table.

The variation in ionization density (in relative units) obtained during the storm is shown in Figure 4.

If it is true that the electrical current in the ionosphere is due to a dynamo effect and that the ion formation rate q is proportional to the intensity I of auroral emission (Ref. 1), the variation in ionization density calculated from the magnetic field should coincide with that calculated from I. The value of N was calculated from I in the following manner.

At each moment of time, N(t) satisfies the ionization balance equation

$$\frac{dN(t)}{dt} = q(t) - \alpha N^2(t).$$

This equation was solved by numerical integration; the chief parameters that determine the ion formation rate and the recombination rate were determined from the following considerations. In Figure 4 it is evident that the maxima of N are delayed relative to the maxima of I by 3 to 10 minutes. Inasmuch as at the moment of a maximum $N(dN/dt) = 0$, $q(t) = -\alpha N^2$ and since $\tau = 1/2\alpha N$ (Ref. 7), then

$$q = \frac{1}{4\alpha\tau^2} \quad \text{and} \quad N_{max} = 2q\tau.$$

Thus, there are still three unknown parameters: N_{max}, q and α, which are related to each other in such a way that any one of them uniquely defines the other two. For calculation we used the values shown in the table.

Values of Parameters Used to Plot Curves 1, 2, 3 in Fig. 4

	1	2	3		1	2	3
τ, min	5	10	10	q, $cm^{-3}sec^{-1}$	$3\cdot10^3$	$3\cdot10^2$	$5\cdot10^2$
α, cm^3/sec	$1\cdot10^{-9}$	$2\cdot10^{-9}$	$4\cdot10^{-9}$	N_{max}, cm^{-3}	$1.7\cdot10^6$	$3.9\cdot10^5$	$3.5\cdot10^5$

From Figure 4 it is evident that the curves thus obtained coincide rather well in form with the variation in ionization density calculated from magnetic data. This indicates that the assumptions about the excitation of electric currents in the ionosphere and the relation of their intensity to the auroral intensity are apparently correct. First, auroral intensity measured with the 180° photometer may in fact be considered proportional to the ion formation rate; second, the magnitude of a magnetic disturbance is determined, according to the dynamo theory, both by the intensity of the corpuscular stream and by the velocity of the ionospheric wind.

Since all three curves in Figure 4 are rather close to one another, it is not possible to say with certainty which of the three cases corresponds more closely to reality.

Nonetheless, curve 1 apparently coincides with the curve for N calculated from the magnetic field better than do the others. In this case one obtains a maximum ionization density ($N_{max} = 1.7 \cdot 10^6$ cm^{-3}) which fully meets the requirements of the dynamo theory, which assumes an increase in ionospheric conductivity by a factor of several dozen during a magnetic storm (Ref. 3). In this case $q = 3 \cdot 10^3$ cm^{-3} sec^{-1}, which also does not contradict the data of other authors (Ref. 8).

Thus, as a result of the analysis of the magnetic storm of 1 March 1960, we may draw the following conclusions.

1. The magnitude of a magnetic disturbance is determined by an increase in ionization density as a result of interaction between a corpuscular stream and the earth's atmosphere. This density depends both on the intensity of the stream and on the recombination coefficient.

2. The recombination coefficient turns out to be $(1\text{-}4) \cdot 10^{-9}$ $cm^3/$ sec. This indicates that magnetic disturbances are caused by currents in the E-layer. In addition, as a result of the small magnitude of the recombination coefficient, the density of secondary electrons cannot change rapidly and, consequently, they cannot cause rapid variations in the magnetic field. The origin of these processes can apparently be explained by some processes that are directly related to the primary corpuscular streams.

3. The intensity of a magnetic disturbance is determined, along with other factors, by the velocity of the ionospheric wind, which, considering what was said in point 1 above, is evidence that the mechanism of generation of electric currents in the ionosphere is the dynamo effect.

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participated in processing the results.

ABSTRACT

Calculation of ionospheric parameters during a rather strong magnetic storm is made on the basis of experimental data obtained by the authors at the Loparskaya station (Institute of Atmospheric Physics of the Academy of Sciences USSR) and at the Murmansk Branch of IZMIRAN. The conclusion is made that the dynamo theory explains the observed phenomena rather well. For the concrete case of a single magnetic storm, an attempt is made to take into account the effect of the ionospheric wind on the geomagnetic field and to calculate its diurnal variation.

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